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# Iceland request on evaluation of harvest control rules for a management plan for Icelandic summer-spawning herring (Division 5.a)

## Advice summary

ICES advises that Rule 1 is not considered precautionary under conditions of *Ichthyophonus* outbreaks. The other candidate harvest control rules proposed for herring are considered precautionary and in accordance with the ICES MSY approach.

## Request

On December 22, 2016, ICES received the following request from Iceland.

> *The Government of Iceland is in the process of formally adopting management plans for Icelandic summer spawning herring (5a), ling (5a) and tusk (5a14):*
>
> *The management strategy for Icelandic summer spawning herring, ling and tusk is to maintain the exploitation rate at the rate which is consistent with the precautionary approach and that generates maximum sustainable yield (MSY) in the long term.*
>
> *A part of the management plan is the adoption of harvest control rules (HCR) for the three stocks for setting annual total allowable catch (TAC). The HCR adopted should be precautionary and in accordance with the ICES MSY approach.*
>
> *The generic form of the HCR is the following:*
> 1. *When the spawning stock biomass (SSB) in the assessment year is estimated to be above $SSB_{MGT}$, the TAC in the following fishing year will be set based on a $F_{MGT}$.*
> 2. *When the SSB in the assessment year is estimated to be below $SSB_{MGT}$, the TAC in the following fishing year will be based on $F_{MGT}$* ($SSB_y/SSB_{MGT}$).*
>
> *The value of $SSB_{MGT}$ should be defined in such a way that the estimated SSB in the assessment year when fishing at $F_{MGT}$ has a low probability of being below $SSB_{MGT}$ (<5%). The HCR could also be based on proportion of reference biomass in the assessment year instead of fishing mortality in the advisory year.*
>
> *The work will be carried out by national experts at the Marine and Freshwater Research Institute with input from managers and stakeholders. During this process the HCR will be formed and the stock specific values of $F_{MGT}$ and $SSB_{MGT}$ will be defined. The HCR, along with technical documentation will be submitted to ICES for review by 20th of March 2017.*
>
> *The Government of Iceland requests ICES to evaluate whether these harvest control rules are in accordance with its objectives, given current ICES definition of reference points or any re-evaluation of those points that may occur in the process. For ling and tusk the evaluation should also include review of input data and the applied assessment methodology (Benchmark). It is expected that the ICES advice for 2017/2018 fishing year for Icelandic summer spawning herring (5a), ling (5a) and tusk (5a14) be based on the above mentioned HCR.*

In further correspondence received by ICES on 19 April 2017, ICES was specifically requested to review the following four harvest control rules for herring:

Rule 1 (The current advisory rule*):*

*The spawning stock biomass trigger (MGT $B_{trigger}$) is defined as 273 kt and the target fishing mortality $F_{MGT}$ as 0.22. Fishing mortality is the average for age groups 5 to 14 weighted by stock numbers. In the assessment year (Y) the TAC for the next fishing year (September 1 of year Y to August 31 of year Y+1) is calculated as follows:*

*When $SSB_Y$ is equal or above MGT $B_{trigger}$:*
*$TAC_{Y/y+1}$ based on $F_Y = F_{MGT}$*
*When $SSB_Y$ is below MGT $B_{trigger}$*
*$TAC_{Y/y+1}$ based on $F_Y = F_{MGT} * (SSB_y/MGT\ B_{trigger})$*

Rule 2 (Biomass equivalence of the current advisory rule)*:*
*The spawning stock biomass trigger (MGT $B_{trigger}$) is defined as 273 kt, the reference biomass ($B_{Ref}$) is defined as the biomass of herring aged 4 and older and the harvest rate ($HR_{MGT}$) is set to 0.19. In the assessment year (Y) the TAC in the next fishing year (September 1 of year Y to August 31 of year Y+1) is calculated as follows:*
*When $SSB_Y$ is equal or above MGT $B_{trigger}$:*
*$TAC_{Y/Y+1} = HR_{MGT} * B_{Ref,y}$*
*When $SSB_Y$ is below MGT $B_{trigger}$:*
*$TAC_{Y/Y+1} = HR_{MGT} * (SSB_y/MGT\ B_{trigger}) * B_{ref,y}$*
*$HR_{MGT}$ is reduced by 33% when icthyophonus is detected.*

Rule 3
*The spawning stock biomass trigger (MGT $B_{trigger}$) is defined as 200 kt, the reference biomass ($B_{Ref}$) is defined as the biomass of herring aged 4 and older and the harvest rate ($HR_{MGT}$) is set to 0.17. In the assessment year (Y) the TAC in the next fishing year (September 1 of year Y to August 31 of year Y+1) is calculated as follows:*
*When $SSB_Y$ is equal or above MGT $B_{trigger}$:*
*$TAC_{Y/y+1} = HR_{MGT} * B_{Ref,y}$*
*When $SSB_Y$ is below MGT $B_{trigger}$:*
*$TAC_{Y/y+1} = HR_{MGT} * (SSB_y/MGT\ B_{trigger}) * B_{ref,y}$*
*$HR_{MGT}$ is reduced by 33% when icthyophonus is detected.*

Rule 4
*The spawning stock biomass trigger (MGT $B_{trigger}$) is defined as 150 kt, the reference biomass ($B_{Ref}$) is defined as the biomass of herring aged 4 and older and the harvest rate ($HR_{MGT}$) is set to 0.15. In the assessment year (Y) the TAC in the next fishing year (September 1 of year Y to August 31 of year Y+1) is calculated as follows:*
*When $SSB_Y$ is equal or above MGT $B_{trigger}$:*
*$TAC_{Y/y+1} = HR_{MGT} * B_{Ref,y}$*
*When $SSB_Y$ is below MGT $B_{trigger}$:*
*$TAC_{Y/y+1} = HR_{MGT} * (SSB_y/MGT\ B_{trigger}) * B_{ref,y}$*
*No further action taken during icthyophonus epidemics.*

The present advice deals with the request for herring. The ICES advice on the requests for ling and tusk is available in ICES (2017a,b).

## Elaboration on the advice

*Evaluation of reference points*

The current reference points for the stock are still considered appropriate and, therefore, remain unchanged. The proposed harvest control rules (HCRs) 2, 3, and 4 are not based on fishing mortality (F) but on the harvest rate (HR) relative to stock biomass of herring at age 4 and older. Based on the current HCR evaluation, the HR that results in maximum long-term yield is $HR_{MSY}$ = 0.19 (Figure 1).

*Evaluation of candidate harvest control rules*

The four harvest control rules were tested by simulation, considering scenarios without and with assessment bias. A persistent bias in the assessment has been observed for this stock over the long term, with overestimation of stock biomass

and underestimation of fishing mortality. Given the current absence of evidence to the contrary, the scenario that assumes the bias will persist in the future is the main one on which conclusions are based.

In a baseline scenario without *Ichthyophonus* infection, all four rules result in no more than 5% probability of SSB < $B_{lim}$ in every year in the short, medium, and long term (Rules 1, 2, 3, and 4 in Table 1(a) with bias, and in Table 2(a)).

An *Ichthyophonus* infection outbreak occurred in 2009–2011, resulting in natural mortality exceeding the range of natural mortalities expected under normal conditions. Given the current observation of infection in 2017, it is expected that additional mortality will most likely affect the stock dynamics in the short term. The robustness of the harvest control rules was evaluated assuming *Ichthyophonus* infection will cause increased natural mortality in 2017, 2018, and 2019; it is assumed that, thereafter, a new infection outbreak will start in any given year with a 10% probability, with each outbreak lasting for three consecutive years. Under these circumstances, Rules 2 and 3 still result in no more than 5% probability of SSB < $B_{lim}$ in every year in the short, medium, and long term (Table 1(c) with bias, and Table 2(c)). With Rule 1, this probability is higher than 5% in every year from 2019 onwards. With Rule 4, this probability is between 6% and 8% in 2019–2021; it then decreases and remains below 5% thereafter.

Rule 5, a more precautionary modification of Rule 4 that sets the MGT $B_{trigger}$ at $B_{lim}$ (200 kt) instead of 150 kt, was examined and found to result in probabilities of SSB going below $B_{lim}$ that were very similar to those obtained under Rule 4 (Table 1).

From the above it is concluded that Rules 2–5 can be considered precautionary. Although Rules 4 and 5 result in an initial phase where the probability of SSB < $B_{lim}$ exceeds 5%, the particular condition of the stock merits consideration of special provisions in the ICES criteria for determining management plans as precautionary. Under these provisions, stocks that are currently below $B_{lim}$ at the commencement of a plan are treated slightly differently. The requirement for the probability of SSB < $B_{lim}$ not to exceed 5% in any year is modified so that it applies only after an initial recovery phase. In the case of Icelandic herring, although the stock is not currently below $B_{lim}$, it is not far above $B_{lim}$ and the current infection by *Icthyophonus* is putting further pressure on the stock. ICES considers the current difficult situation affecting the stock to be analogous to that described in the ICES criteria. Under these circumstances, probabilities slightly above 5% only in the first few years, followed by a continuous period with probabilities below 5%, are acceptable. This justifies the decision to consider Rules 4 and 5 precautionary.

Although Rule 1 would be considered precautionary in the scenario without *Ichthyophonus* infection, this does not remain the case under the conditions of *Ichthyophonus* outbreaks that seem prevalent at present.

Long-term equilibrium yield curves versus harvest rate or F (Figures 1 and 2) indicate a rather flat top, with the values of $HR_{MGT}$ = 0.19, 0.17, 0.15 (Rules 2, 3, and 4/5) or $F_{MGT}$ = 0.22 (Rule 1) corresponding to yields that are within 3% of the maximum yield. Rules 2–5 are, therefore, considered to be in accordance with the ICES MSY approach. Rule 1 is not considered precautionary under the conditions of *Ichthyophonus* outbreaks. Being precautionary is a prerequisite for conformity with the ICES MSY approach and, therefore, Rule 1 is not considered to be in accordance with the ICES MSY approach.

## Basis of the advice

### Background

The request is based on the work of an *ad hoc* group of scientists from the Marine and Freshwater Research Institute (MFRI), initiated by the Icelandic Ministry of Industries and Innovation in the summer of 2016. The objective of the group was to investigate harvest control rules for herring, ling, and tusk that would be in conformity with the precautionary approach and ICES MSY framework, and to maintain a long-term high sustainable yield.

ICES set up a workshop (ICES, 2017c) to evaluate the proposed harvest control rules.

**Results and conclusions**

The harvest control rules were tested by simulation, considering scenarios without and with assessment bias, based on the patterns observed in the past. With the present length of the survey series used in the assessment, the bias is estimated to be around 15%. Given the current absence of evidence to the contrary, the scenario that assumes the bias will persist in the future is the main one on which conclusions are based. Because of the *Ichthyophonus* infection outbreak that occurred in 2009–2011 and is again happening in 2017, scenarios that incorporate possible increases in natural mortality caused by further epidemics are considered to be an important part of the evaluation and have an impact on the conclusions drawn.

Figures 1 and 2 display long-term equilibrium results and indicate that, in the absence of epidemics, the target harvest rates (Rules 2, 3, and 4/5) or fishing mortality (Rule 1) in the rules all result in long-term yields at, or close to the maximum sustainable yield, and less than 5% probability of SSB < $B_{lim}$ in the long term.

The situation, however, is complicated because of the possible periods of increased natural mortality that may be expected as a consequence of future *Ichthyophonus* infection outbreaks. Relevant short- and long-term statistics are presented in Tables 1 and 2.

In the baseline scenario of no *Ichthyophonus* outbreaks, all rules result in less than 5% probability of SSB < $B_{lim}$ (Table 1(a), and Table 2(a) and 2(b)).

If assessment bias is assumed in combination with possible *Ichthyophonus* outbreaks (10% probability that an infectious outbreak, lasting for three consecutive years, starts in any given year), then Rule 1 results in more than 5% probability of SSB < $B_{lim}$ in most years (Table 1(b) and 1(c)), including in the long term (see Table 2(c), which shows that the 5th percentile of SSB is below $B_{lim}$ = 200 kt). Therefore, Rule 1 is not considered precautionary under conditions of *Ichthyophonus* outbreaks. Under the same scenario of assessment bias in combination with possible *Ichthyophonus* outbreaks, and conditioning on an epidemic taking place during 2017–2019, Rules 4 and 5 result in 6%–8% probability of SSB < $B_{lim}$ in the years 2019–2021 (Table 1(c)); the probability is less than 5% in all subsequent years, including in the long term (Table 2(c)). As explained earlier in this document, taking into account the current stock situation, probabilities slightly above 5% only in the first few years, followed by a continuous period with probabilities below 5%, are acceptable; therefore, Rules 4 and 5 are considered precautionary. Rules 2 and 3 resulted in less than 5% probability of SSB < $B_{lim}$ in all years for all scenarios tested and are, therefore, the most robust rules relative to the precautionary criterion.

Figures 3 and 4 graphically illustrate the development of SSB and catches under the HCRs, for the scenario that assumes 15% assessment bias and *Ichthyophonus* epidemic outbreaks.

The inclusion of the MGT $B_{trigger}$ in the proposed HCRs is considered important to reduce the risk of depletion of the stock in periods of poor recruitment. If the SSB declines below $B_{lim}$, the rate of stock recovery is improved if the HR is reduced below MGT $B_{trigger}$. Under normal circumstances this MGT $B_{trigger}$ will only be very rarely encountered for rules that have low HR and low MGT $B_{trigger}$ (such as Rules 3, 4, and 5), but will be encountered more often for rules that have higher HR and higher MGT $B_{trigger}$ (such as Rule 2).

The rules with the lowest harvest rate (Rule 4 and 5) have the lowest average catch (Table 3), but also the most stable catch and the least interannual variability in catch (Table 4). Stock size is also the largest with these rules (Figure 3).

The expected distributions of the B4+ biomass, SSB, fishing pressure, and catches for the different rules are shown in Table 2. These distributions should be used in the future to check that realised ranges are compatible with expectations. If future observed values were to go outside the range illustrated, this would indicate that there is a need to re-evaluate the assumptions of the simulations.

**Table 1** Results for harvest control rules 1–4 in the request, with an additional rule 5 (Rule 5 is the same as Rule 4, except that MGT $B_{trigger}$ = 200 kt = $B_{lim}$). Annual probabilities of SSB going below $B_{lim}$ = 200 kt, with and without 15% assessment bias. The following *Ichthyophonus* scenarios are considered: (a) no epidemic in the coming years, (b) 10% probability of a 3-year epidemic starting in any given year, and (c) an epidemic definitely takes place in 2017–2019, followed by a 10% probability of a new 3-year epidemic starting in any given year. Values above 0.05 (i.e. 5%) are highlighted in bold.

| **(a) No *Ichthyophonus* epidemic** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Bias = 0 | | | | | | | | | |
| Rule | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 |
| Rule-1 | 0.009 | 0.004 | 0.007 | 0.005 | 0.002 | 0.003 | 0.004 | 0.006 | 0.005 |
| Rule-2 | 0.009 | 0.005 | 0.008 | 0.005 | 0.003 | 0.003 | 0.004 | 0.005 | 0.005 |
| Rule-3 | 0.008 | 0.004 | 0.005 | 0.004 | 0.002 | 0.002 | 0.001 | 0.000 | 0.004 |
| Rule-4 | 0.005 | 0.003 | 0.004 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Rule-5 | 0.005 | 0.003 | 0.004 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Bias = 15% | | | | | | | | | |
| Rule | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 |
| Rule-1 | 0.019 | 0.010 | 0.013 | 0.013 | 0.018 | 0.025 | 0.017 | 0.019 | 0.023 |
| Rule-2 | 0.021 | 0.012 | 0.013 | 0.016 | 0.020 | 0.025 | 0.018 | 0.019 | 0.024 |
| Rule-3 | 0.012 | 0.007 | 0.009 | 0.006 | 0.011 | 0.007 | 0.006 | 0.011 | 0.010 |
| Rule-4 | 0.008 | 0.004 | 0.004 | 0.005 | 0.003 | 0.002 | 0.000 | 0.000 | 0.003 |
| Rule-5 | 0.008 | 0.004 | 0.004 | 0.005 | 0.003 | 0.002 | 0.000 | 0.000 | 0.003 |
| **(b) 10% probability of *Ichthyophonus* all years** | | | | | | | | | |
| Bias = 0 | | | | | | | | | |
| Rule | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 |
| Rule-1 | 0.023 | 0.026 | 0.024 | 0.024 | 0.02 | 0.018 | 0.019 | 0.021 | 0.029 |
| Rule-2 | 0.015 | 0.011 | 0.011 | 0.014 | 0.008 | 0.011 | 0.008 | 0.009 | 0.017 |
| Rule-3 | 0.014 | 0.010 | 0.006 | 0.009 | 0.007 | 0.006 | 0.004 | 0.006 | 0.012 |
| Rule-4 | 0.019 | 0.020 | 0.018 | 0.017 | 0.014 | 0.012 | 0.006 | 0.012 | 0.017 |
| Rule-5 | 0.019 | 0.019 | 0.016 | 0.016 | 0.013 | 0.010 | 0.005 | 0.011 | 0.016 |
| Bias = 15% | | | | | | | | | |
| Rule | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 |
| Rule-1 | 0.032 | 0.041 | 0.038 | 0.037 | 0.050 | **0.057** | **0.052** | **0.055** | **0.06** |
| Rule-2 | 0.022 | 0.025 | 0.025 | 0.027 | 0.027 | 0.031 | 0.025 | 0.03 | 0.033 |
| Rule-3 | 0.021 | 0.016 | 0.017 | 0.017 | 0.017 | 0.019 | 0.013 | 0.019 | 0.025 |
| Rule-4 | 0.025 | 0.029 | 0.023 | 0.027 | 0.024 | 0.025 | 0.019 | 0.025 | 0.027 |
| Rule-5 | 0.025 | 0.029 | 0.022 | 0.027 | 0.024 | 0.024 | 0.017 | 0.023 | 0.027 |
| **(c) *Ichthyophonus* epidemic in 2017–2019 and 10% probability of epidemic after 2019** | | | | | | | | | |
| Bias = 0 | | | | | | | | | |
| Rule | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 |
| Rule-1 | 0.029 | 0.045 | **0.068** | 0.046 | 0.037 | 0.037 | 0.031 | 0.032 | 0.036 |
| Rule-2 | 0.017 | 0.016 | 0.027 | 0.018 | 0.017 | 0.016 | 0.011 | 0.017 | 0.021 |
| Rule-3 | 0.014 | 0.017 | 0.026 | 0.013 | 0.017 | 0.010 | 0.009 | 0.010 | 0.018 |
| Rule-4 | 0.027 | 0.034 | **0.056** | 0.038 | 0.027 | 0.027 | 0.02 | 0.022 | 0.021 |
| Rule-5 | 0.026 | 0.031 | **0.054** | 0.036 | 0.026 | 0.023 | 0.016 | 0.017 | 0.020 |
| Bias = 15% | | | | | | | | | |
| Rule | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 |
| Rule-1 | 0.044 | **0.089** | **0.126** | **0.089** | **0.081** | **0.082** | **0.078** | **0.075** | **0.078** |
| Rule-2 | 0.02 | 0.027 | 0.049 | 0.040 | 0.039 | 0.039 | 0.033 | 0.037 | 0.041 |
| Rule-3 | 0.017 | 0.024 | 0.037 | 0.026 | 0.027 | 0.025 | 0.019 | 0.022 | 0.030 |
| Rule-4 | 0.036 | **0.060** | **0.083** | **0.058** | 0.045 | 0.049 | 0.045 | 0.044 | 0.046 |
| Rule-5 | 0.036 | **0.059** | **0.081** | **0.056** | 0.043 | 0.044 | 0.038 | 0.039 | 0.045 |

**Table 2** Results for the harvest control rules evaluated (note: HCR 5 behaves very similarly to HCR 4). Percentiles (5%, 16%, 50%, 84%, and 95%) of the long-term simulations with and without 15% assessment bias. The following *Ichthyophonus* scenarios are considered: no epidemic (panels a and b); epidemic, i.e. an epidemic in 2017–2019 followed by a 10% probability of a new 3-year epidemic starting in any given year (panels c and d).

| **(a) Bias = 15% and no *Ichthyophonus* epidemic** | | | | | | | **(b) Bias = 0 and no *Ichthyophonus* epidemic** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fishing mortality** | | | | | | | | | | | |
| Rule | 5% | 16% | 50% | 84% | 95% | | 5% | 16% | 50% | 84% | 95% |
| Rule-1 | 0.166 | 0.196 | 0.255 | 0.334 | 0.397 | | 0.133 | 0.162 | 0.218 | 0.294 | 0.354 |
| Rule-2 | 0.159 | 0.189 | 0.248 | 0.329 | 0.394 | | 0.125 | 0.154 | 0.21 | 0.286 | 0.348 |
| Rule-3 | 0.146 | 0.169 | 0.219 | 0.287 | 0.343 | | 0.116 | 0.138 | 0.185 | 0.25 | 0.303 |
| Rule-4 | 0.126 | 0.146 | 0.188 | 0.246 | 0.293 | | 0.1 | 0.119 | 0.159 | 0.214 | 0.259 |
| **Harvest rate** | | | | | | | | | | | |
| Rule | 5% | 16% | 50% | 84% | 95% | | 5% | 16% | 50% | 84% | 95% |
| Rule-2 | 0.148 | 0.173 | 0.216 | 0.271 | 0.312 | | 0.12 | 0.145 | 0.188 | 0.243 | 0.284 |
| Rule-3 | 0.138 | 0.158 | 0.195 | 0.243 | 0.28 | | 0.112 | 0.133 | 0.169 | 0.218 | 0.255 |
| Rule-4 | 0.122 | 0.14 | 0.172 | 0.214 | 0.247 | | 0.099 | 0.117 | 0.149 | 0.192 | 0.225 |
| **SSB (kt)** | | | | | | | | | | | |
| Rule | 5% | 16% | 50% | 84% | 95% | | 5% | 16% | 50% | 84% | 95% |
| Rule-1 | 235 | 289 | 390 | 523 | 622 | | 272 | 334 | 444 | 590 | 700 |
| Rule-2 | 232 | 286 | 387 | 519 | 617 | | 271 | 331 | 442 | 586 | 696 |
| Rule-3 | 260 | 319 | 428 | 568 | 671 | | 300 | 366 | 485 | 638 | 756 |
| Rule-4 | 300 | 364 | 480 | 627 | 739 | | 341 | 412 | 540 | 702 | 825 |
| **Biomass age 4+** | | | | | | | | | | | |
| Rule | 5% | 16% | 50% | 84% | 95% | | 5% | 16% | 50% | 84% | 95% |
| Rule-2 | 259 | 321 | 433 | 583 | 693 | | 299 | 366 | 488 | 647 | 765 |
| Rule-3 | 288 | 354 | 475 | 629 | 744 | | 329 | 400 | 531 | 698 | 820 |
| Rule-4 | 330 | 398 | 525 | 686 | 808 | | 371 | 446 | 584 | 759 | 888 |
| **Catch (kt)** | | | | | | | | | | | |
| Rule | 5% | 16% | 50% | 84% | 95% | | 5% | 16% | 50% | 84% | 95% |
| Rule-1 | 51 | 68 | 94 | 128 | 157 | | 49 | 66 | 91 | 125 | 154 |
| Rule-2 | 50 | 68 | 95 | 131 | 161 | | 48 | 66 | 92 | 128 | 158 |
| Rule-3 | 54 | 67 | 93 | 127 | 156 | | 52 | 64 | 90 | 124 | 153 |
| Rule-4 | 54 | 66 | 91 | 123 | 150 | | 51 | 63 | 87 | 120 | 147 |

| **(c) Bias = 15% and *Ichthyophonus* epidemic** | | | | | | | **(d) Bias = 0 and *Ichthyophonus* epidemic** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fishing mortality** | | | | | | | | | | | |
| Rule | 5% | 16% | 50% | 84% | 95% | | 5% | 16% | 50% | 84% | 95% |
| Rule-1 | 0.152 | 0.187 | 0.25 | 0.331 | 0.393 | | 0.121 | 0.154 | 0.214 | 0.291 | 0.352 |
| Rule-2 | 0.124 | 0.159 | 0.224 | 0.309 | 0.376 | | 0.099 | 0.13 | 0.189 | 0.268 | 0.332 |
| Rule-3 | 0.118 | 0.146 | 0.199 | 0.271 | 0.329 | | 0.097 | 0.12 | 0.168 | 0.235 | 0.29 |
| Rule-4 | 0.129 | 0.15 | 0.194 | 0.254 | 0.304 | | 0.103 | 0.123 | 0.164 | 0.221 | 0.268 |
| **Harvest rate** | | | | | | | | | | | |
| Rule | 5% | 16% | 50% | 84% | 95% | | 5% | 16% | 50% | 84% | 95% |
| Rule-2 | 0.112 | 0.143 | 0.197 | 0.257 | 0.3 | | 0.093 | 0.119 | 0.17 | 0.229 | 0.273 |
| Rule-3 | 0.107 | 0.131 | 0.178 | 0.231 | 0.27 | | 0.09 | 0.111 | 0.154 | 0.205 | 0.244 |
| Rule-4 | 0.122 | 0.139 | 0.172 | 0.214 | 0.247 | | 0.099 | 0.117 | 0.149 | 0.192 | 0.225 |
| **SSB (kt)** | | | | | | | | | | | |
| Rule | 5% | 16% | 50% | 84% | 95% | | 5% | 16% | 50% | 84% | 95% |
| Rule-1 | 190 | 245 | 342 | 476 | 576 | | 222 | 282 | 390 | 535 | 644 |
| Rule-2 | 210 | 265 | 363 | 493 | 588 | | 243 | 303 | 410 | 550 | 655 |
| Rule-3 | 227 | 291 | 398 | 534 | 635 | | 259 | 327 | 444 | 592 | 704 |
| Rule-4 | 218 | 291 | 410 | 560 | 671 | | 248 | 328 | 458 | 622 | 744 |
| **Biomass age 4+** | | | | | | | | | | | |
| Rule | 5% | 16% | 50% | 84% | 95% | | 5% | 16% | 50% | 84% | 95% |
| Rule-2 | 229 | 292 | 401 | 549 | 658 | | 260 | 329 | 448 | 604 | 719 |
| Rule-3 | 246 | 316 | 435 | 588 | 702 | | 278 | 353 | 480 | 644 | 765 |
| Rule-4 | 235 | 316 | 448 | 617 | 736 | | 267 | 352 | 494 | 673 | 804 |
| **Catch (kt)** (kt) | | | | | | | | | | | |
| Rule | 5% | 16% | 50% | 84% | 95% | | 5% | 16% | 50% | 84% | 95% |
| Rule-1 | 34 | 53 | 81 | 115 | 143 | | 33 | 51 | 79 | 112 | 140 |
| Rule-2 | 34 | 50 | 79 | 117 | 147 | | 32 | 48 | 77 | 113 | 143 |
| Rule-3 | 37 | 50 | 77 | 113 | 141 | | 35 | 48 | 74 | 108 | 137 |
| Rule-4 | 40 | 53 | 77 | 109 | 136 | | 38 | 50 | 74 | 105 | 132 |

**Table 3** Average, median, 10th percentile, 5th percentile, and standard deviation of the catches (kt) in the long run (assuming 15% assessment bias and 10% probability of *Ichtyophonus* starting in each given year; Rule 5 is the same as Rule 4, except that MGT $B_{trigger}$ = 200 kt = $B_{lim}$).

| | Average | Median | 10th percentile | 5th percentile | Standard deviation |
|---|---|---|---|---|---|
| Rule 1 | 84 | 80.8 | 43.4 | 33.5 | 33.1 |
| Rule 2 | 83.6 | 79.5 | 42.4 | 33.6 | 34.9 |
| Rule 3 | 81.6 | 77.2 | 43.9 | 36.8 | 32.7 |
| Rule 4 | 81.3 | 77.5 | 46.9 | 39.9 | 30 |
| Rule 5 | 81.3 | 77.5 | 47.2 | 40.2 | 30.1 |

**Table 4** Relative interannual variability in catches in the long run, measured as the percentage change in catch between consecutive years (assuming 15% assessment bias and 10% probability of *Ichtyophonus* starting in each given year; Rule 5 is the same as Rule 4, except that MGT $B_{trigger}$ = 200 kt = $B_{lim}$). The table shows the 5th, 10th, 25th, 75th, 90th, and 95th percentiles of the change. The bold values correspond to a decrease in catch. As an example, using Rule 4 there is a 5% probability of 32.8% or more reduction in catches from one year to the next.

| Rule | **5%** | **10%** | **25%** | 75% | 90% | 95% |
|---|---|---|---|---|---|---|
| Rule 1 | **36.2** | **29.1** | **16.2** | 18.5 | 41.6 | 59.7 |
| Rule 2 | **40.8** | **32.6** | **18.1** | 21.7 | 48.1 | 69.1 |
| Rule 3 | **36.9** | **29.8** | **16.6** | 19.4 | 42.2 | 58.9 |
| Rule 4 | **32.8** | **26.5** | **14.8** | 17.1 | 35.8 | 49 |
| Rule 5 | **33.2** | **26.8** | **15** | 17.3 | 36.3 | 49.8 |

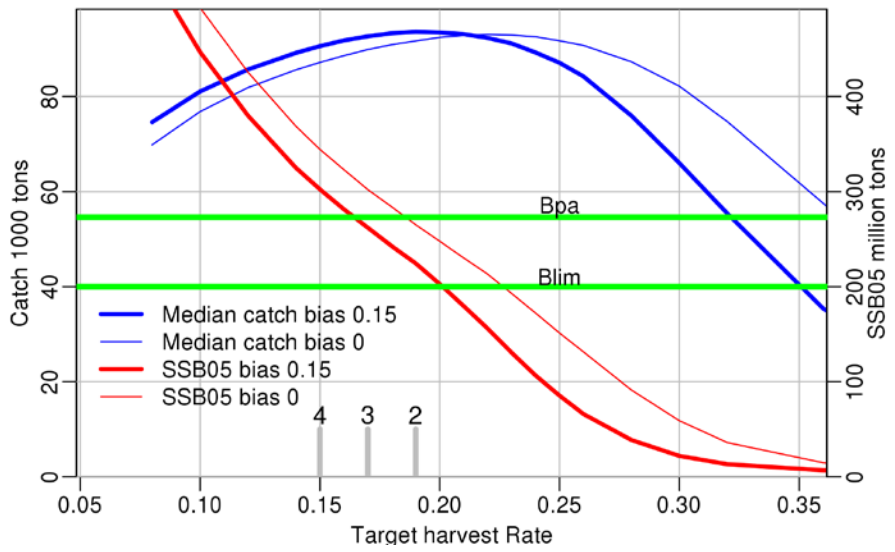



**Figure 1** Median catch and fifth percentile of SSB at equilibrium (long term) for different harvest rates, with and without assuming 15% assessment bias. No increase in natural mortality from *Ichthyophonus* epidemics. Harvest rates corresponding to HCRs 2, 3, and 4/5 (0.19, 0.17, and 0.15, respectively) are shown. HR = 0.19 maximizes the median catch when a 15% assessment bias is assumed. No $B_{trigger}$ was applied.

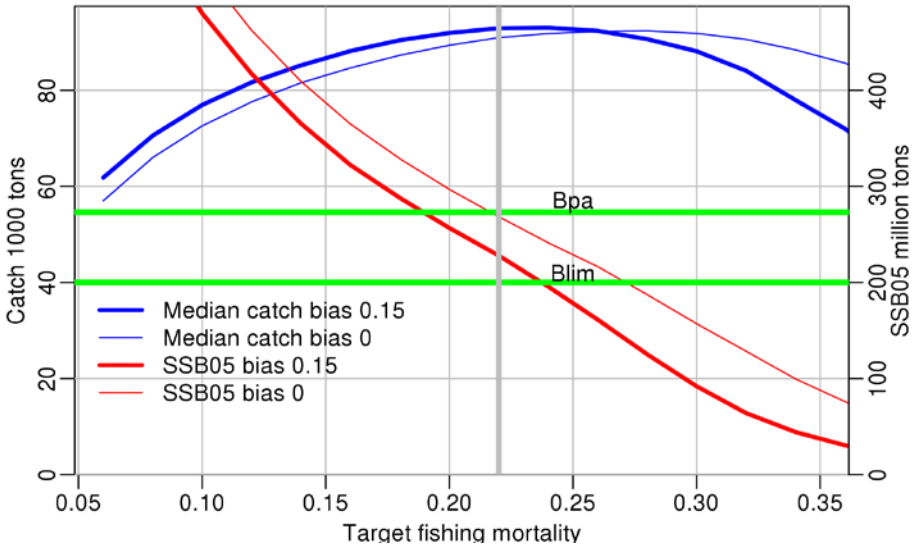



**Figure 2** Median catch and fifth percentile of SSB at equilibrium (long term) for different fishing mortalities, with and without assuming 15% assessment bias. No increase in natural mortality from *Ichthyophonus* epidemics. The vertical line corresponds to $F_{MSY}$ = 0.22. No $B_{trigger}$ was applied.

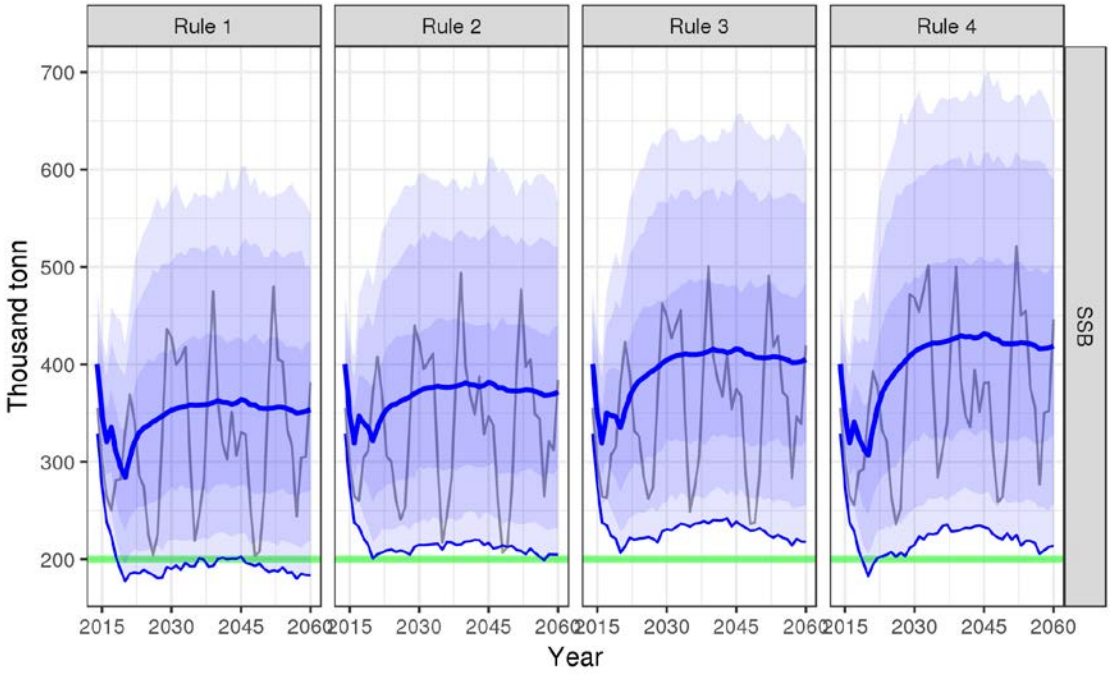



**Figure 3** Development of SSB for the different HCRs (note: HCR 5 behaves very similarly to HCR 4). The shaded areas show the 5th, 10th, 25th, 75th, 90th, and 95th percentiles, and the thick blue lines the median. One individual run is shown. The horizontal lines show $B_{lim}$ = 200 kt. Assessment bias is 15% and the scenario assumes an *Ichthyophonus* epidemic during 2017–2019 followed by a 10% probability that a new 3-year epidemic starts in any given year.

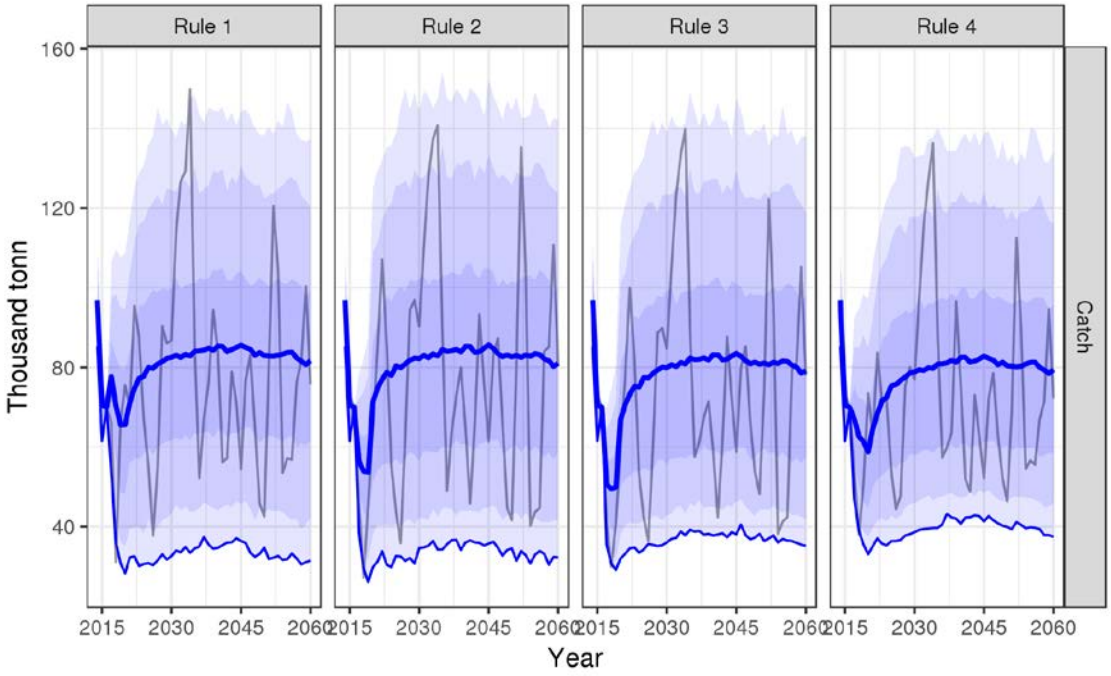



**Figure 4** Development of catch for the different HCRs (note: HCR 5 behaves very similarly to HCR 4). The shaded areas show the 5th, 10th, 25th, 75th, 90th, and 95th percentiles, and the thick blue lines the median. One individual run is shown. Assessment bias is 15% and the scenario assumes an *Ichthyophonus* epidemic during 2017–2019 followed by a 10% probability that a new 3-year epidemic starts in any given year.

**Methods**

A Management Strategy Evaluation (MSE) was conducted for the Icelandic summer-spawning herring stock, using computer code that has been used in earlier evaluation of Icelandic cod, haddock, and saithe. The assessment model used to condition the simulation framework is not the same as currently used in the annual assessment of the stock (VPA-Adapt). However, historical estimates of key metrics, including biomass estimates and retrospective pattern, were similar for the two methods, and the approach is considered appropriate for the purpose of the MSE. The input data included catch numbers-at-age from 1947 to 2015 and age-disaggregated survey indices from 1987 to 2015. Maturity (fixed) and selection were based on the average of the last 20 years. Future recruitment was simulated from a hockey-stick stock–recruitment function with annual deviations, autocorrelated in time, and fish weights were simulated stochastically, with autocorrelated noise. The MSE runs were conducted with both fixed natural mortality of 0.1 (i.e. no mortality due to *Ichthyophonus* epidemics) and with different scenarios of continuation of *Ichthyophonus* epidemics. In the epidemics scenarios, additional natural mortality due to *Ichthyophonus* infection was set at the level estimated for 2009–2011; the epidemics were assumed to start randomly, with 10% probability in any given year, and to last for three consecutive years. In addition to this, in one of the scenarios, an epidemic was assumed to occur with complete certainty (100% probability) during 2017–2019.

The assessment error of the reference biomass (corresponding to herring aged 4 and older) and spawning biomass in the assessment year were based on estimates from empirical retrospective patterns of the analytical assessment, and resulted in bias of 15% (overestimation of stock biomass). Stochastic error, autocorrelated in time, was then added to the bias term. When rules based on harvest rates are applied (Rules 2–5), no short-term forecast is required because the annual TAC is based on the harvest rate as a proportion of the age 4+ biomass in the beginning of the assessment year. In these rules, the spawning stock, in July, is predicted from the results of the assessment, using half the annual natural mortality of a normal year without *Ichthyophonus* mortality (i.e. 0.05). The rule based on fishing mortality (Rule 1) applies a short-term forecast to calculate catch in the fishing year, which goes from 1 September to 31 August; the natural mortality assumed when applying this rule is increased in years when an *Ichthyophonus* epidemic is known to be occurring. Weight-at-age has to be predicted for all the HCRs and prediction error is taken into account by using the weights-at-age of the previous year.

The analyses were based on 1000 iterations for each harvest rate or HCR rule.

## Sources and references

ICES. 2017a. Iceland request to evaluate the HCR for ling in Division 5.a. *In* Report of the ICES Advisory Committee, 2017. ICES Advice 2017, sr.2017.09.

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ICES. 2017c. Report of the Workshop on Evaluation of the Adopted Harvest Control Rules for Icelandic Summer Spawning Herring, Ling and Tusk (WKICEMSE), 21–25 April 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:45. 196 pp.